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Lithium-Boiling Potassium Refractor Metal Loop Facillty

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ABSTRACT

A 30-kw lithium-boiling potassium two-loop facility is presently under construction at the Jet Propulsion Laboratory and is expected to be in operation during 1964.

The loop is totally constructed of columbium-1% zirconium alloy and will operate at temperatures up to 2100°F.

The primary purposes of this loop facility are as follows:

1. To investigate over-all transient and steady-state characteristics of a two-loop system which approximately simulates velocities, temperature, pressures, transit times, and heat fluxes in the range of actual system interest. The primary loop heat source is by direct-resistance heat generation in a section of tube wall and liquid metal, which lends itself to programming of reactor kinetic equations for simulation of power response to various system perturbations. A detailed study of regimes of boiling stability under various operating conditions, heat fluxes, exit vapor quality, inlet subcooling, etc. will be made.

2. To obtain steady-state local-boiling heat-transfer coefficients and two-phase pressure drop data for a variety of operating parameters.

3. To evaluate components such as throttling valves, centrifugal pumps, hot traps, and experimental turbine-alternators for potential application to actual systems.

I. AREAS OF INVESTIGATION

The two-loop lithium-boiling potassium facility under construction at JPL represents an attempt to simulate the major elements of a two-loop nuclear turboplant concept of potential interest for spacecraft propulsion. The primary purpose of this facility is to investigate over-all transient and steady-state characteristics of a Rankine cycle alkali metal plant which approximately simulates operating conditions of actual system interest. Various programmed startups, power demand transients, control concepts for power range operation, etc. will be studied in parallel with an attempt to predict and/or formulate the necessary models to predict system behavior by analog representation.

In addition to the system dynamic program, a study will be attempted to define regimes of boiling stability as affected by various operating conditions, heat fluxes, exit vapor quality, inlet subcooling, liquid and two-phase pressure drop distribution, and other pertinent parameters. Various types of boilers are contemplated for investigation including tube-side boilers and shell-side cross-flow boilers. Steady-state local and over-all heat transfer coefficients and pressure drop data will also be obtained for a variety of boiler configurations and operating conditions.

Finally, a facility of this nature is, of necessity, engaged in component evaluation. Items such as throttling valves, centrifugal pumps, hot traps, liquid vapor separators, and experimental turbine-alternator components will be evaluated for potential application to space power systems.

II. LOOP DESIGN

Figure 1 is a flow schematic of the system, and Table 1 shows the loop operating conditions. Briefly, the primary side lithium flow enters a direct current resistance-heated helical coil to which reactor kinetic equations may be programmed for simulation of power response to various system perturbations. The lithium enters a centrifugal pump which employs a combination recirculation and liquid level indicator sump, through a bellows seal throttle valve, electromagnetic flowmeter, boiler, and returns to the heater inlet. About 15% of the flow is bypassed to an yttrium hot trap located in the coolest part of the system to minimize mass transfer effects.

The secondary side potassium enters a countercurrent annular flow boiler, exits through a flow orifice to the experimental turbine or bypass bellows seal vapor throttling valve, to a radiating condenser. The condenser is surrounded by an array of rotating radiation shields to

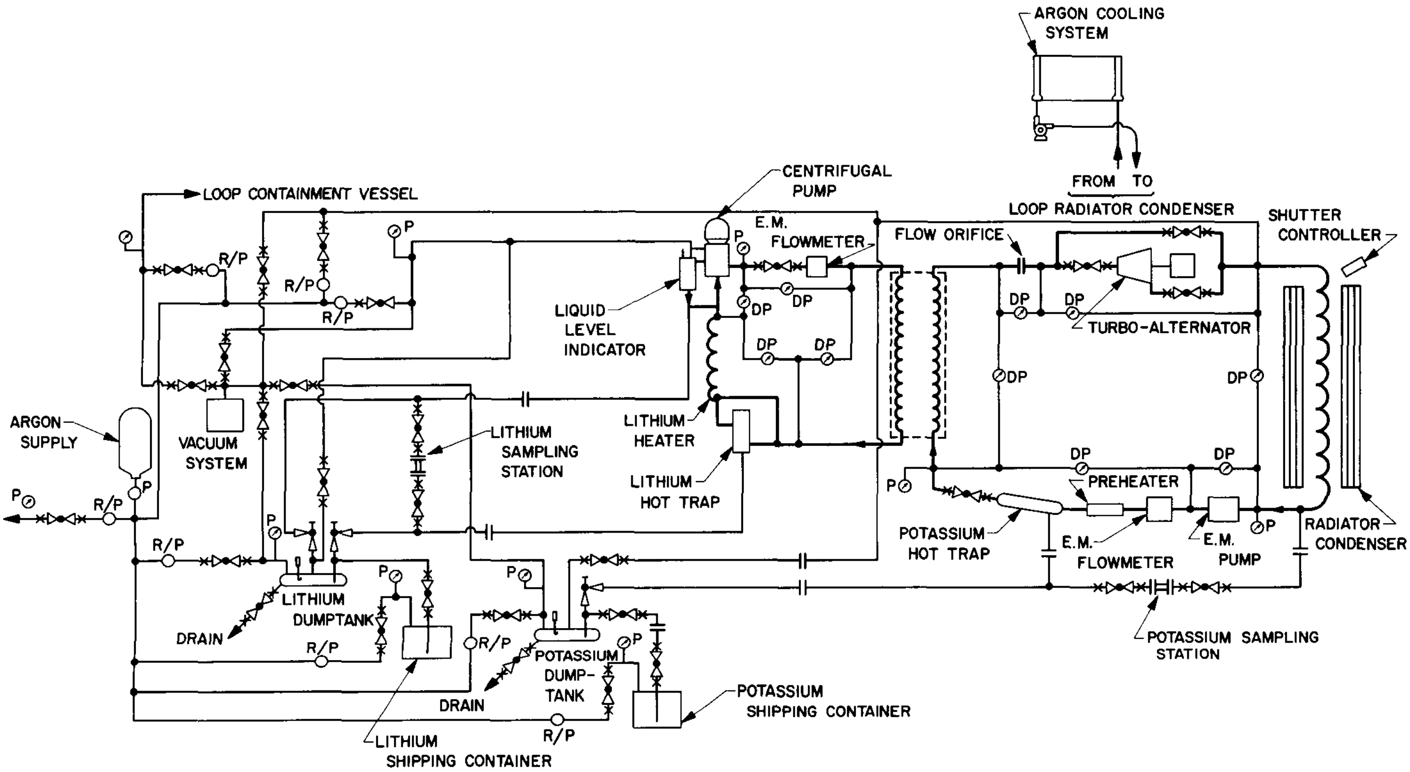


Fig. 1. Lithium-boiling potassium loop

vary the effective condenser area. The potassium continues through a subcooler electromagnetic pump, electromagnetic flowmeter, preheater, zirconium gettered hot trap, liquid throttle valve, and returns to the boiler inlet.

The loop is contained in a 5-ft diameter by 7-ft long main enclosure with auxiliary enclosures for the condensing radiator and fill/dump system as shown in Fig. 2. The system will be run in a recirculating argon atmosphere slightly above atmospheric pressure. Make-up argon will have an oxygen content of about 1 ppm oxygen and ½ ppm water vapor. Equilibrium concentration in the enclosure is expected to be several orders of magnitude below these figures and unmeasurable by continuous-stream analysis techniques.

The loop will be triple-tantalum-foil wrapped and insulated with about 3 in. of "Glass Rock" foamed high-purity silica.

All materials that come in contact with fluids above 1500°F will be Cb-1Zr with the exception of higher-alloy valve facings, hot trap getters, and turbine wheel. The fill and dump system is constructed of Type 304 stainless steel.

Table 1. 30 kw — 2100°F loop

Item	Operating conditions	Supplier and type
Lithium (liquid)		Foote Mineral Co.
Flow rate, Gpm	1 to 10	
Temperature, °F	2100	
Pressure, PSIG	Up to 20	
Potassium (liquid)		MSA Research Corp.
Flow rate, Gpm	0 to 1	
Temperature, °F	1500 to 2000	
Pressure, PSIG	Up to 200	
Centrifugal pump (lithium)	Up to 10 Gpm at 100 ft (TDH) 2100°F Service	Byron-Jackson
Swing gate valves (bellows seal)		Valcor Engineering Co.
Lithium	2100°F Li service	5/8 in. OD
Potassium	2000°F boiling K service	3/4 in. Sch. 80
EM flowmeters		MSA flowmeter FM-4
Lithium	2100°F service	5/8 in. OD 1/16 in. wall Cb — 1% Zr duct
Potassium	1500°F service	3/8 in. OD Cb — 1% Zr duct
Diaphragm	Li and K pressure measurements	Cb — 1% Zr
K—boiler	Loop design conditions	JPL
K—vapor separator	Loop design conditions	———
Dump tanks and valves (Argon, vacuum and fill)	500°F service	Material S.S. 304

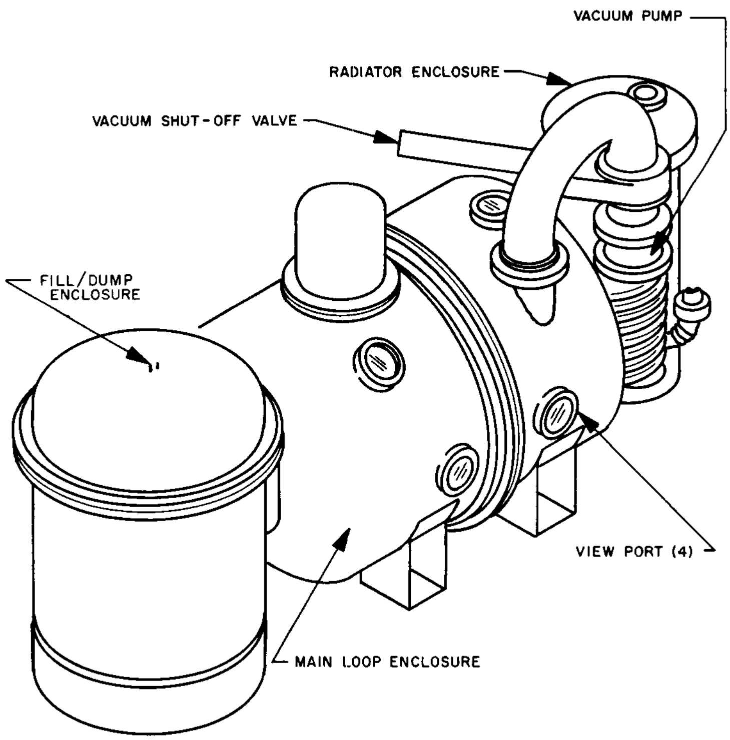


Fig. 2. Lithium-boiling potassium loop enclosure

III. LOOP COMPONENTS

The design of loop and auxiliary components is essentially complete. All components and/or materials have been purchased for assembly of the loop. The development and fabrication of a test isolation diaphragm assembly for pressure measurements have been completed, and a test program has been initiated. Compatibility experiments are in progress to evaluate various potential loop insulation materials. Difficulties encountered in hydroforming Cb-1Zr bellows have resulted in the investigation of alternate forming techniques, including a coreduction vapor deposition process.

Major loop components are shown in Fig. 3 through 10.

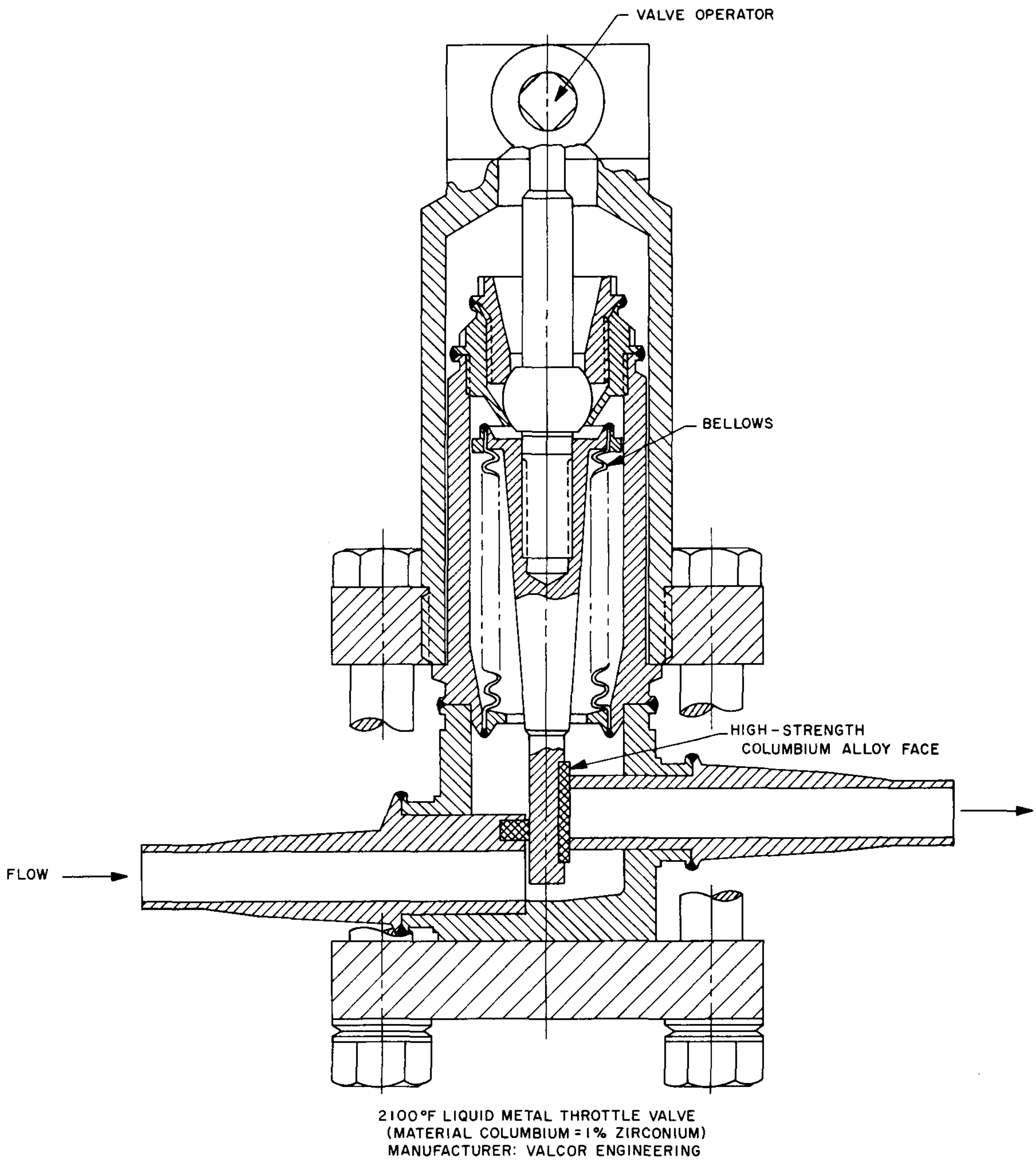


Fig. 3. Lithium-boiling potassium loop valve design

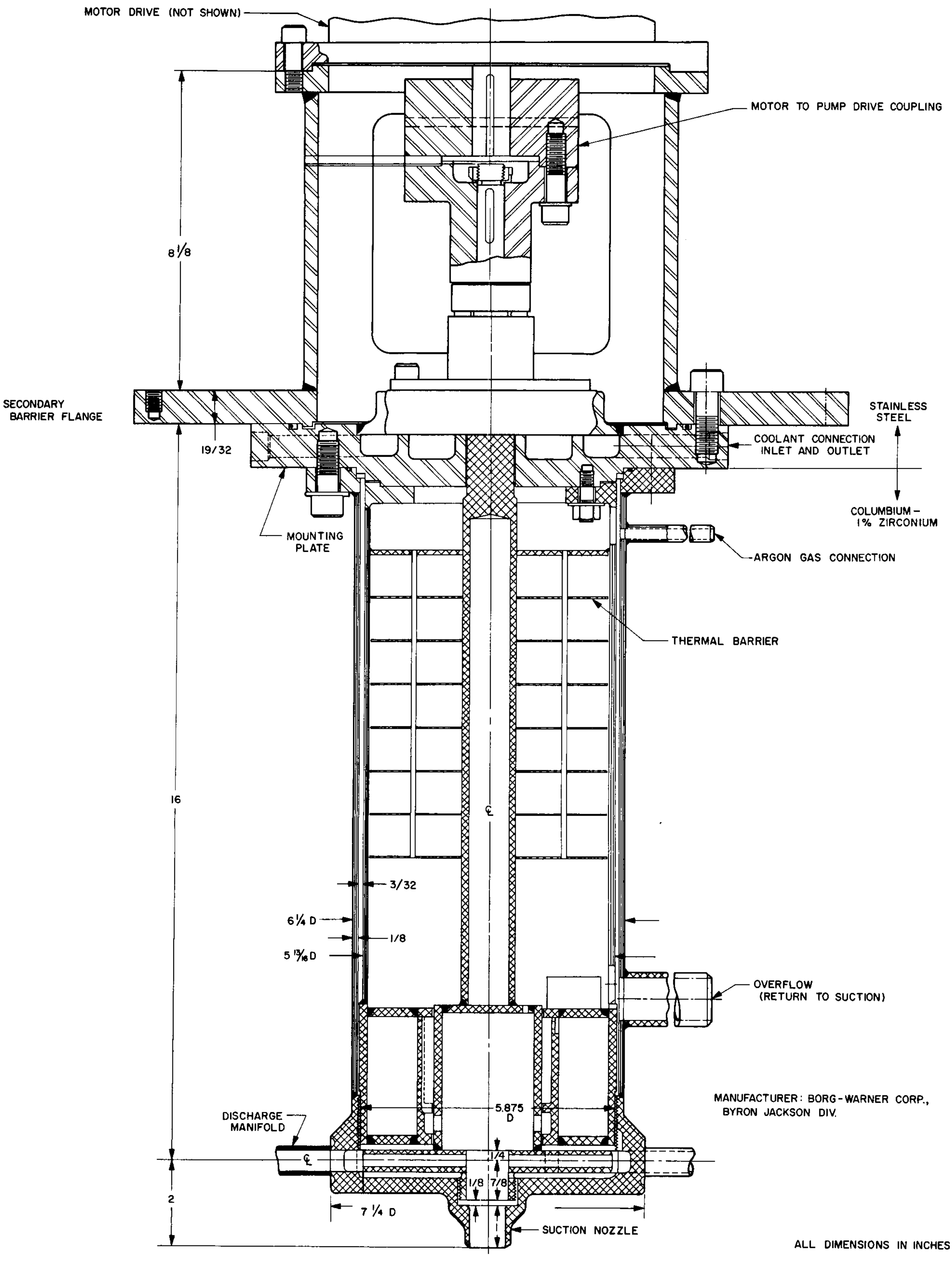
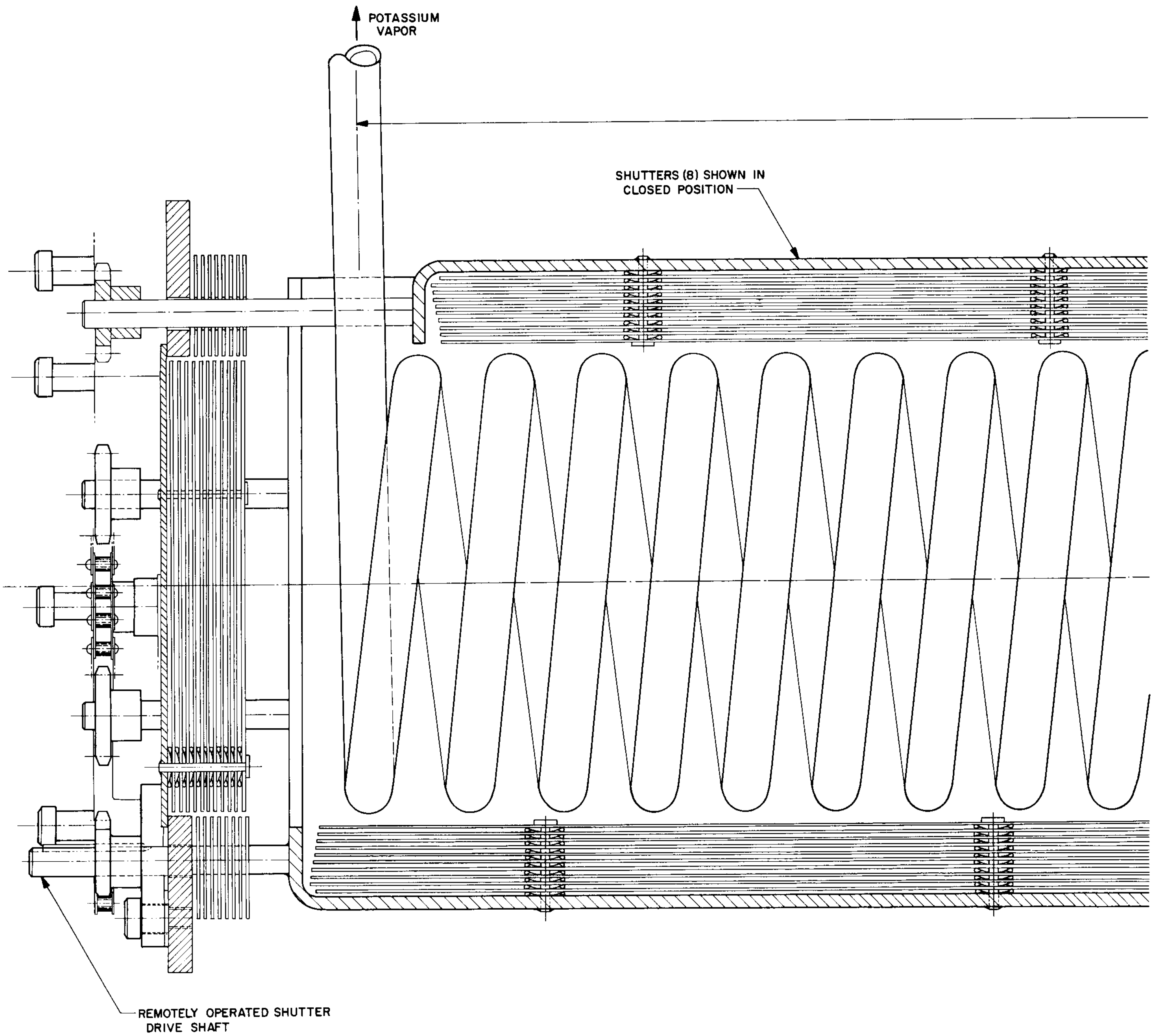


Fig. 4. 2100°F liquid metal centrifugal pump


POTASSIUM VAPOR
SHUTTERS (8) SHOWN IN CLOSED POSITION
REMOTELY OPERATED SHUTTER DRIVE SHAFT

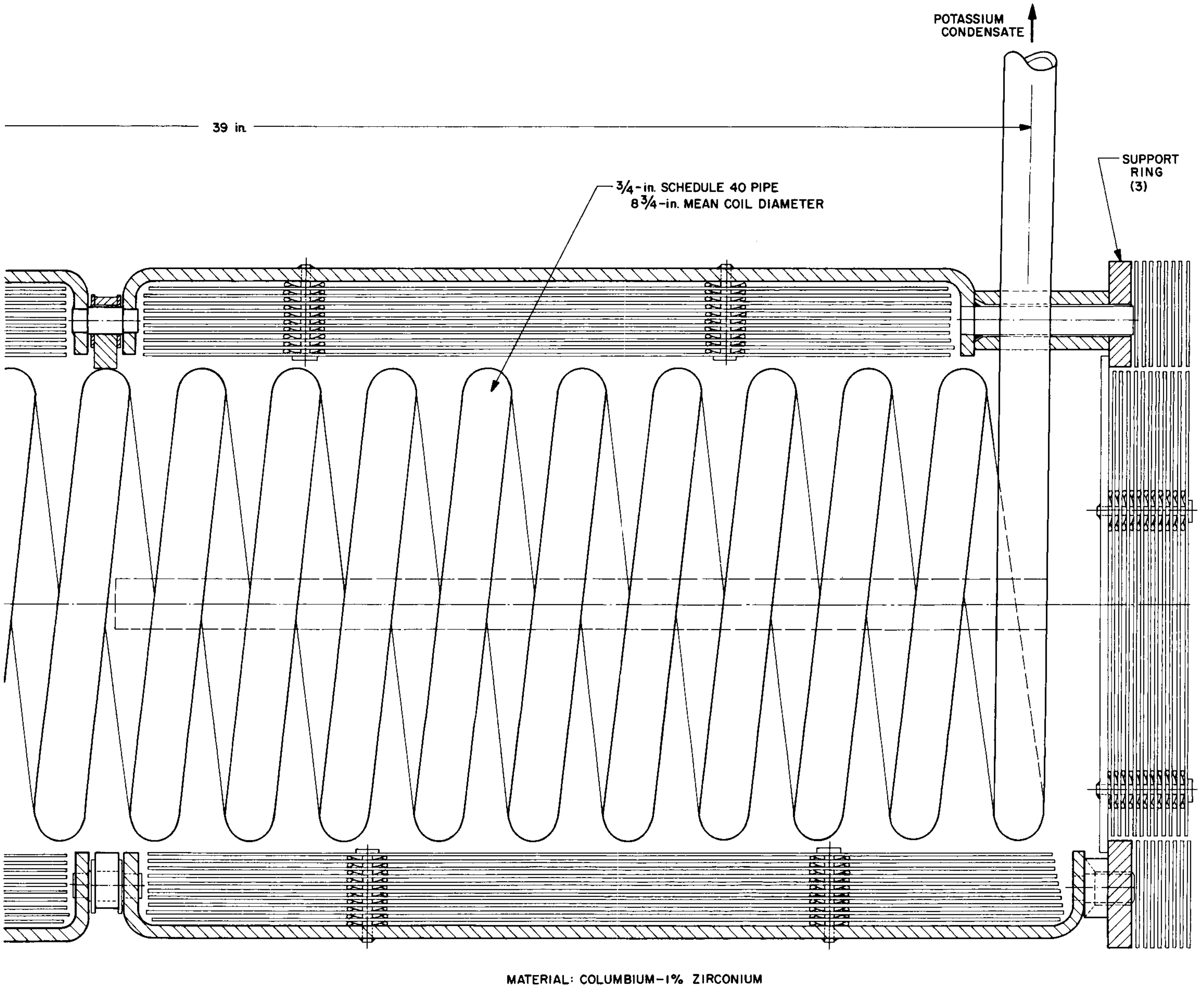


Fig. 5. Lithium-boiling potassium loop radiator and control shutter assembly, lower half

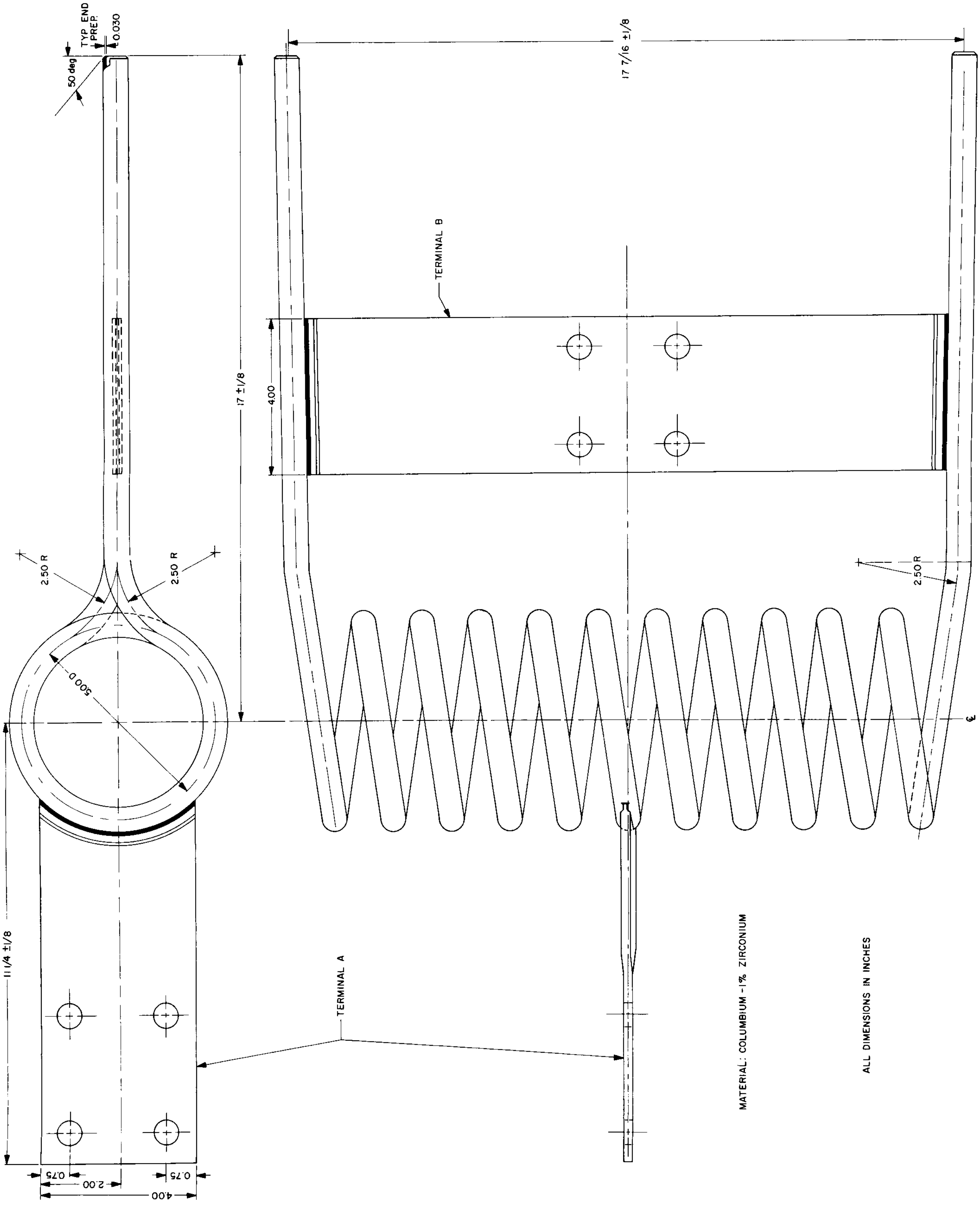


Fig. 6. Lithium circuit direct resistance heating coil

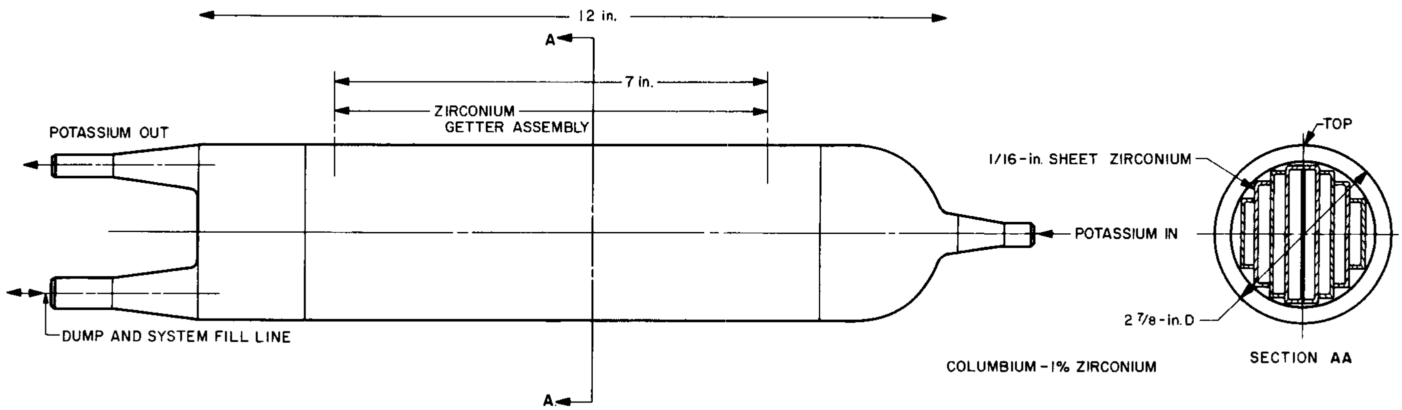


Fig. 7. Potassium circuit hold-up and hot trap assembly

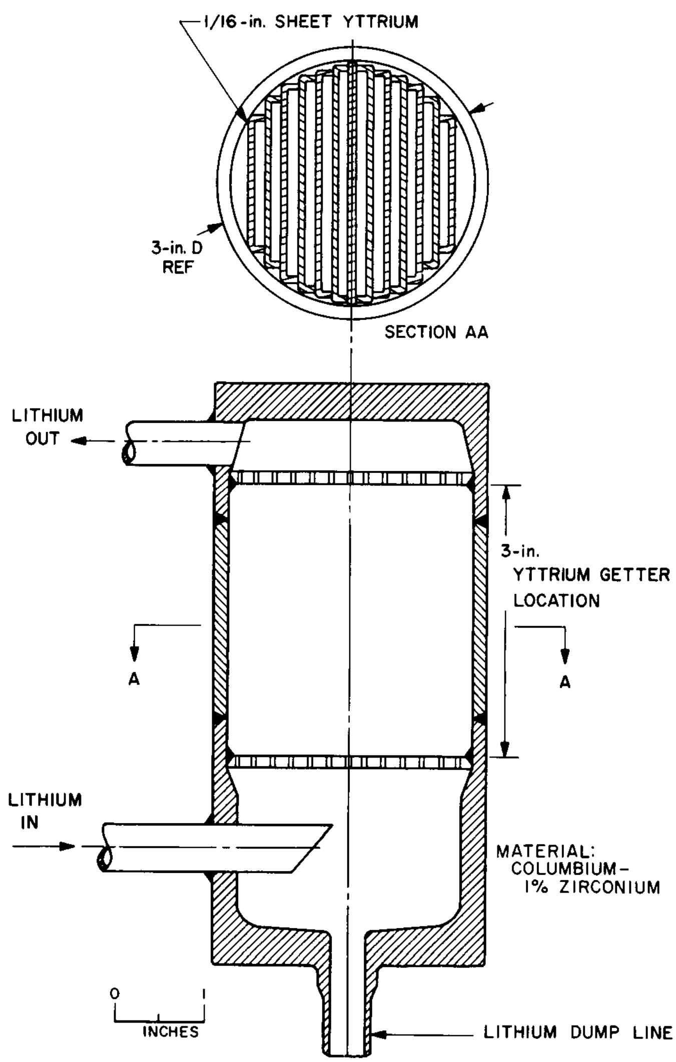


Fig. 8. Lithium circuit hot trap assembly

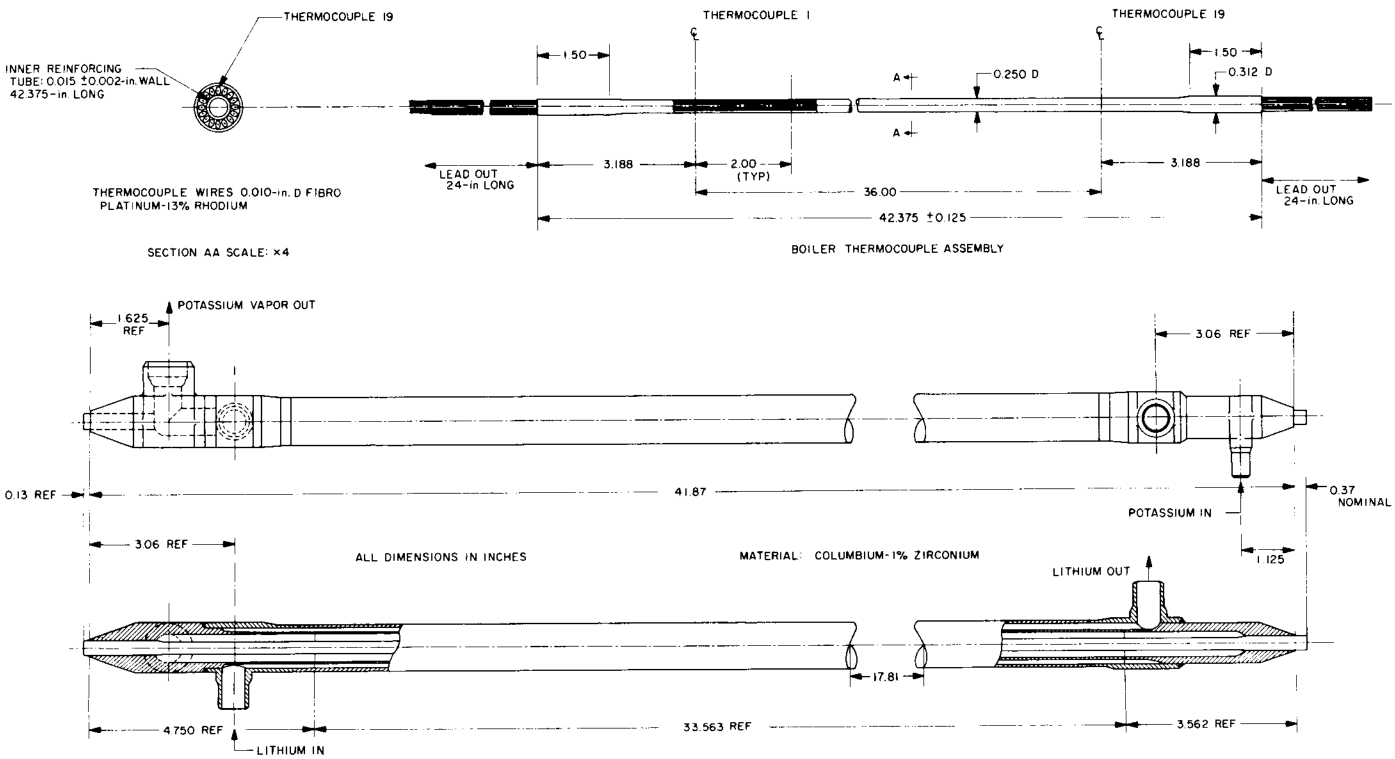


Fig. 9. Lithium-boiling potassium loop boiler assembly

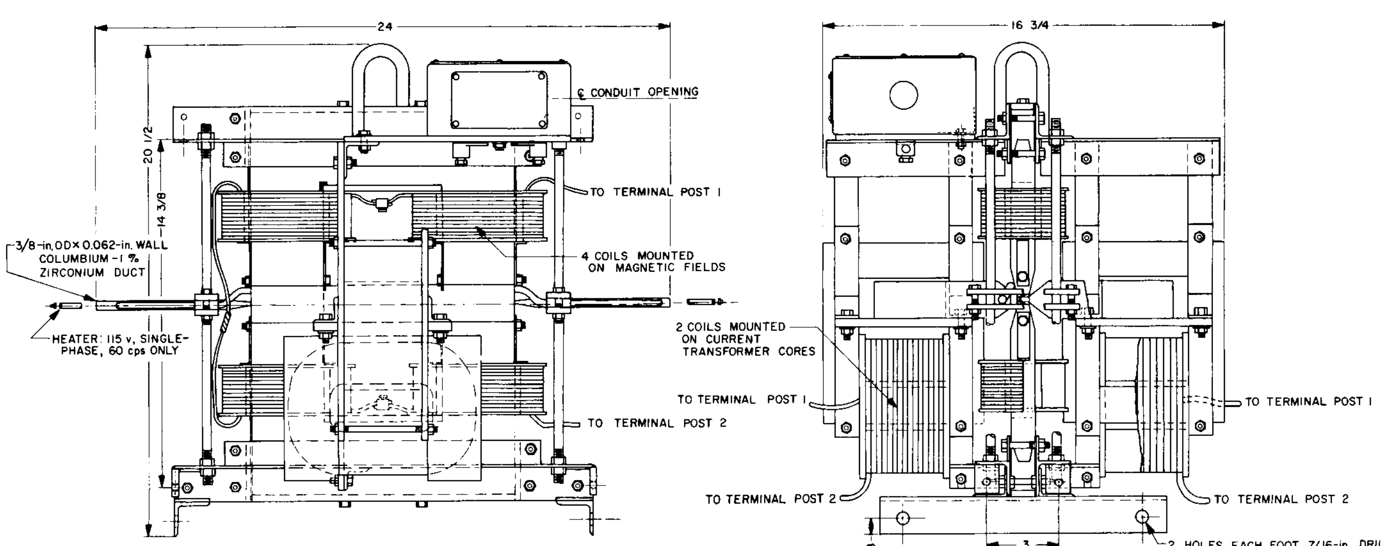


Fig. 10. Electromagnetic pump assembly

IV. FABRICATION STATUS

The loop design has been mocked up as a full-scale assembly, shown in Fig. 11. The purpose of this mockup is for locating components, associated piping and electrical wiring, heater power leads, piping supports, and the fitting up of insulation.

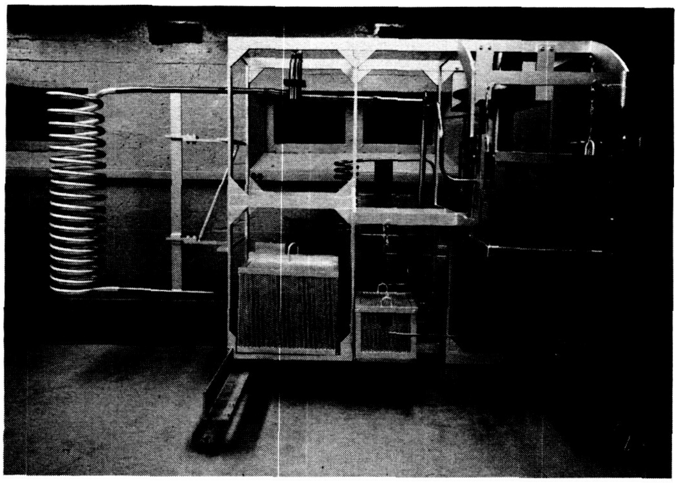


Fig. 11. Lithium-boiling potassium loop mock-up

The loop is designed to permit the fabrication and assembly of the various loop components on the loop support frame outside the loop containment vessel. The containment vessel itself, shown in Fig. 12, is composed of two major sections, one of which can be traversed on tracks to permit the installation of the loop assembly and the associated power, instrumentation and dump system feedthroughs. The control shutter assembly shown on its preassembly stand, Fig. 13 and 14, will be installed in the vertical section of the movable portion of the con-

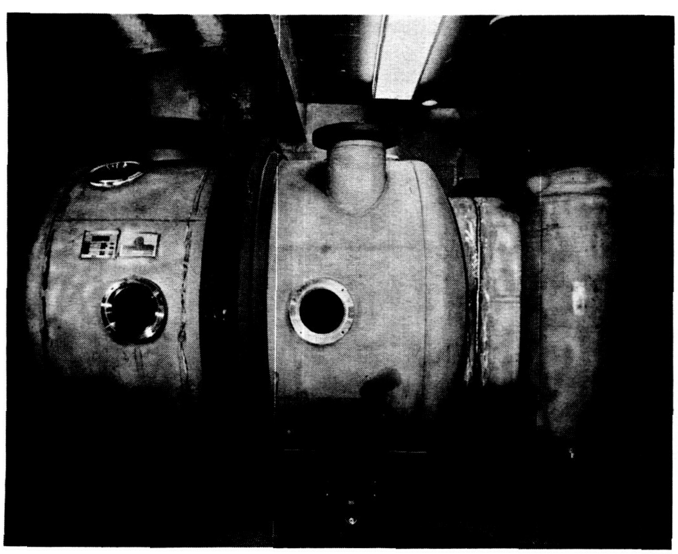


Fig. 12. Lithium-boiling potassium loop containment vessel

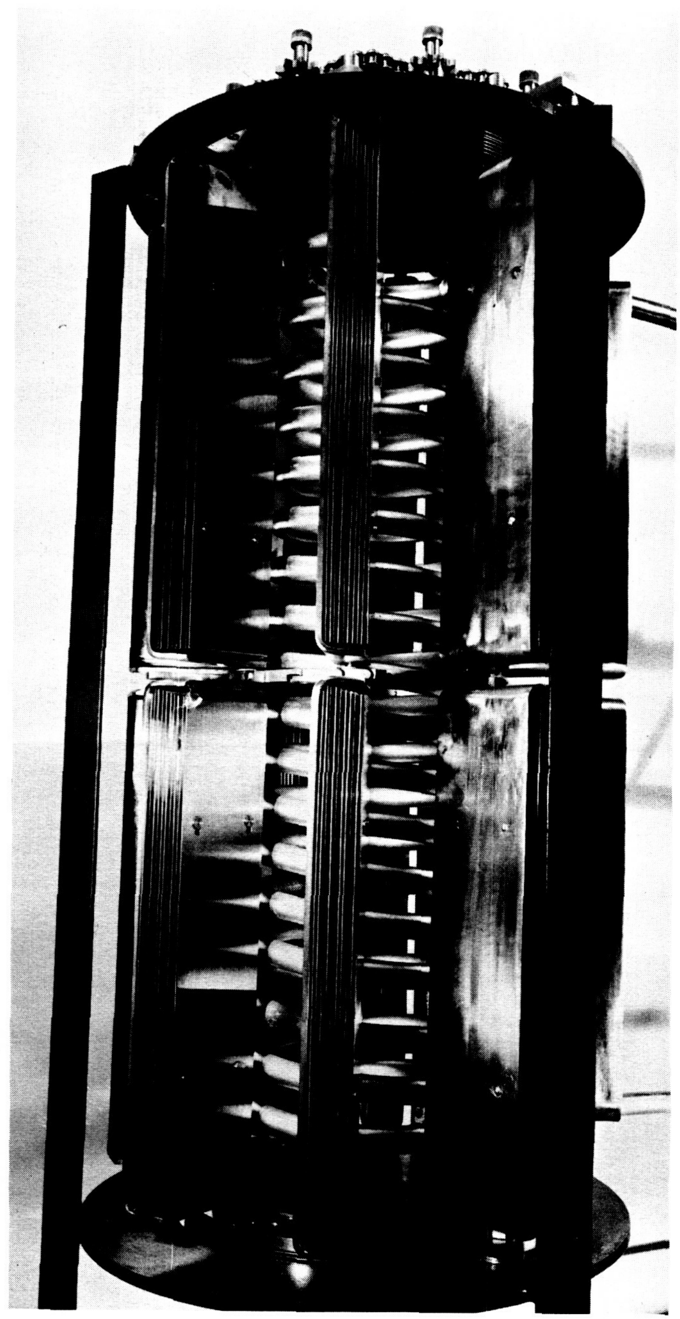


Fig. 13. Radiator shutter assembly-open position

tainment vessel. The lithium circuit and potassium circuit hot traps and the lithium circuit liquid level indicator have been machined and are shown in Fig. 15, 16 and 17. The loop boiler assembly is being fabricated at JPL. The lithium and potassium electromagnetic flowmeters and the potassium electromagnetic pump have been delivered, and test preparations are in progress for calibration. All other components are in final fabrication.

The vacuum, argon cooling and dump systems are shown in Fig. 18, 19 and 20, in various stages of construction.

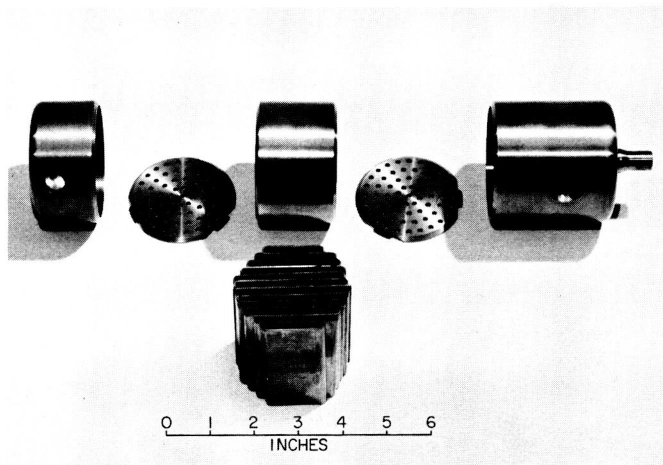


Fig. 15. Lithium circuit hot trap assembly

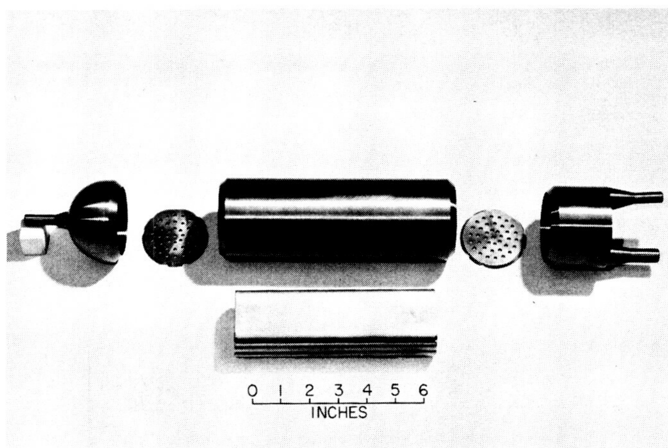


Fig. 16. Potassium circuit hot trap assembly

Fig. 14. Radiator shutter assembly-closed position

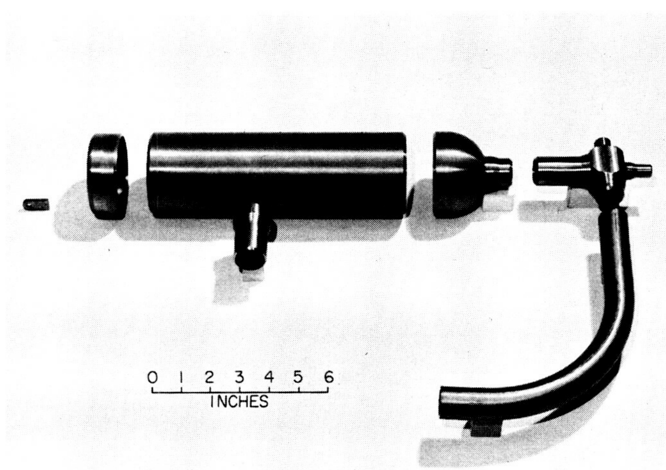


Fig. 17. Lithium circuit liquid level indicator assembly

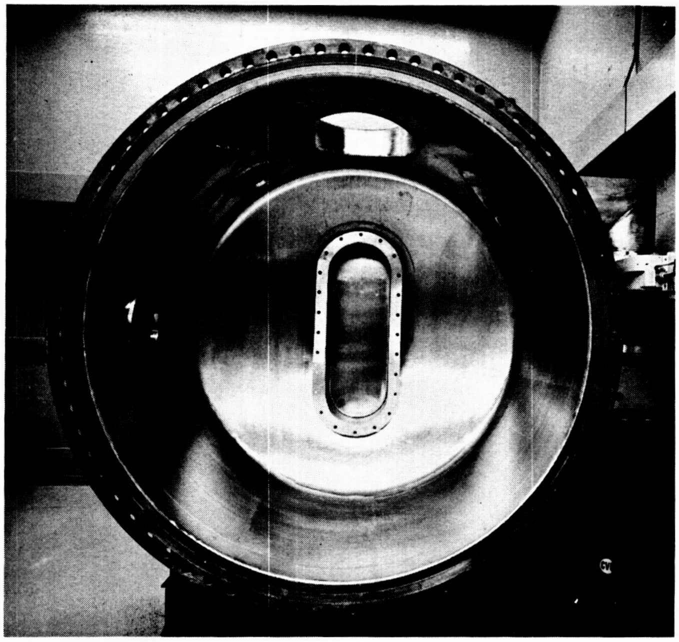


Fig. 18. 10-in. Vacuum system, attached to stationary section of containment vessel

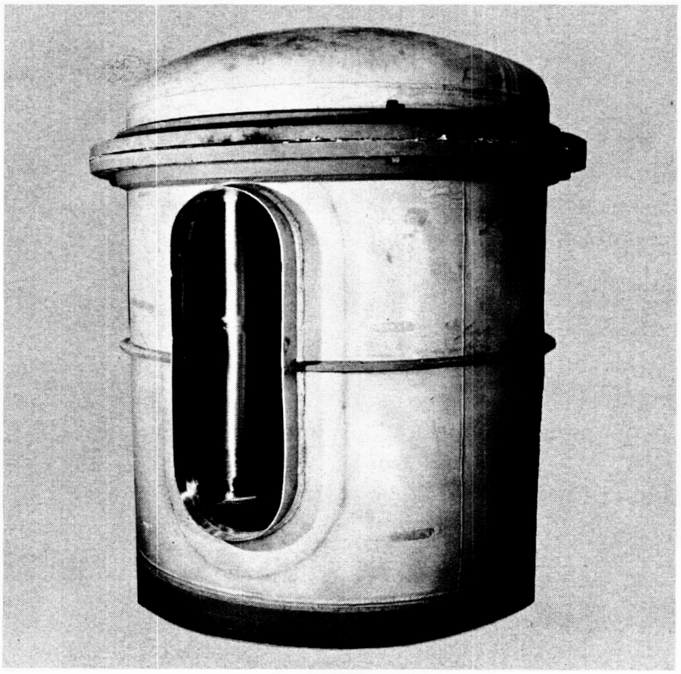


Fig. 19. Loop dump system containment vessel

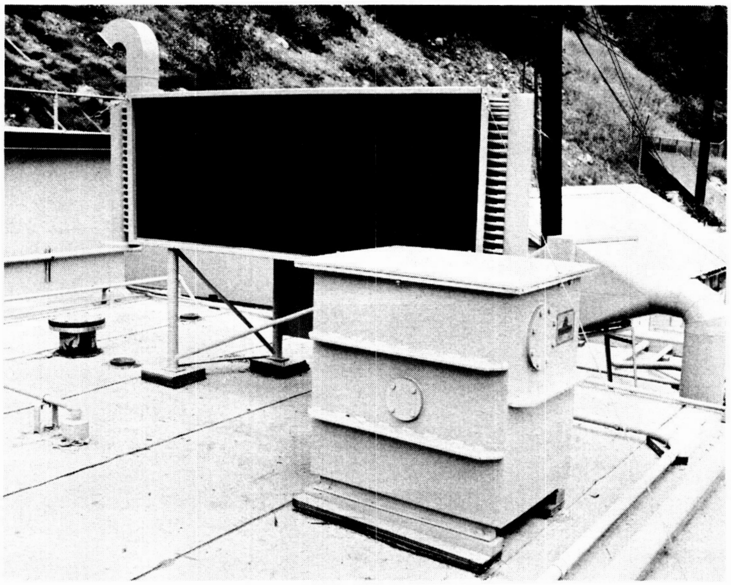


Fig. 20. Loop argon cooler and blower assembly

V. MATERIALS SUPPORT FACILITIES

The corrosion and compatibility test facility consists of three 3.2 kw Glowbar type furnaces (Fig. 21) containing two atmosphere test chambers, each (six independent experiments) manufactured by Hevi-Duty Electric Co. These furnaces are independently connected to a tilting mechanism capable of tilting 45° from the horizontal, from 1 to 4 cycles/min, as well as static operation, for long-time compatibility experiments at temperatures up to 2500°F. Associated equipment consists of a 16-point temperature recorder, alkali metal and radiological leak detectors, and an oxygen analyzer. The test chamber atmosphere is continuously monitored.

Fig. 21. Tilting furnace assembly

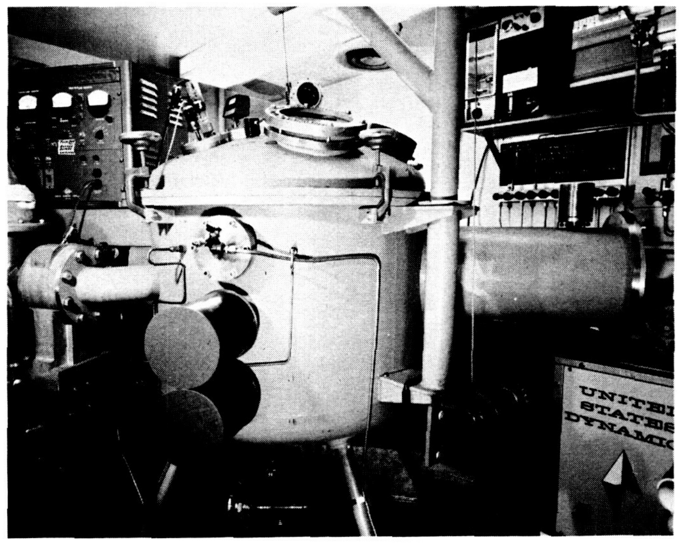


Fig. 22. TIG welding drybox with purification and analysis equipment

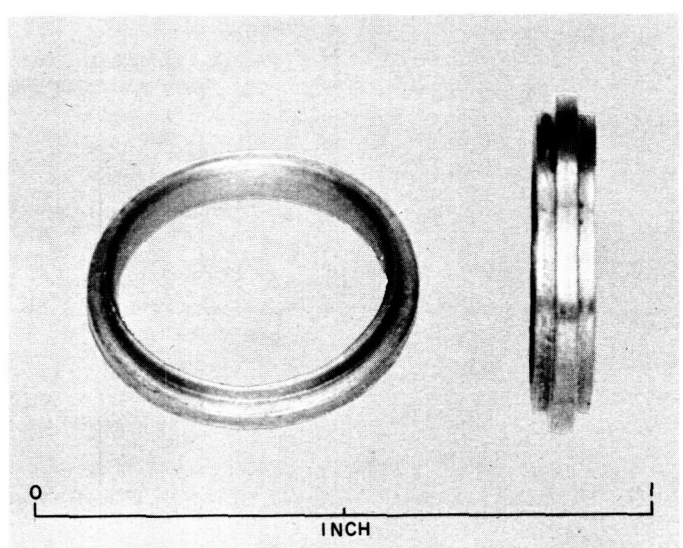


Fig. 23. Cb-1Zr welding inserts for ⅝-in. tubing

A TIG welding facility, including gas purification and moisture analysis equipment, is presently in operation (Fig. 22). Monitoring of the argon welding atmosphere, both before and after welding, indicates that moisture and oxygen impurity levels are readily maintained below 2 ppm.

The use of welding inserts (Fig. 23) for butt-welding tubing has proven satisfactory. Metallographic examination of these welds indicates melting and complete bonding of the tubing-insert interface have taken place. The insert, however, did not melt sufficiently to allow the metal to flow toward the inner surface of the tubing, as is commonly observed with stainless steel. As a result, the shape of the welding insert is retained on the inner surface of the tube. The welds produced with this technique were consistent, and the discontinuities produced on the inner surface of the tube were approximately the same size as with standard butt-weld techniques.

Due to previously observed hardening of Cb-1Zr from contact with foamed silica, evaluation of other insulations was undertaken. Samples of insulation were outgassed at 2000°F for 24 hr under a cover of argon gas. Two tensile specimens of Cb-1Zr in contact with a sample of insulation were placed in direct contact with the insulation. In the others the tensile specimens and insulation were separated by tantalum foil to simulate loop conditions.

The following types of insulation have been tested: Cercor (a product of Corning Glass Works), Glassrock Foam #25, and Foamsil. These insulations as received, after outgassing and after testing, are shown in Fig. 24, 25 and 26. Results of tensile and microhardness measurements are shown in Table 2. Metallographic examination showed no effect of contamination on microstructure. Microhardness measurements indicated that surface hardening had taken place, and tensile tests indicated that a slight amount of strengthening had also taken place.

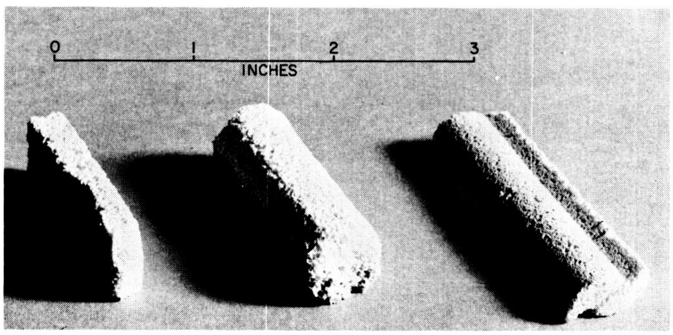


Fig. 24. Glassrock foam No. 25 as received after outgassing at 2000°F and after testing at 2200°F

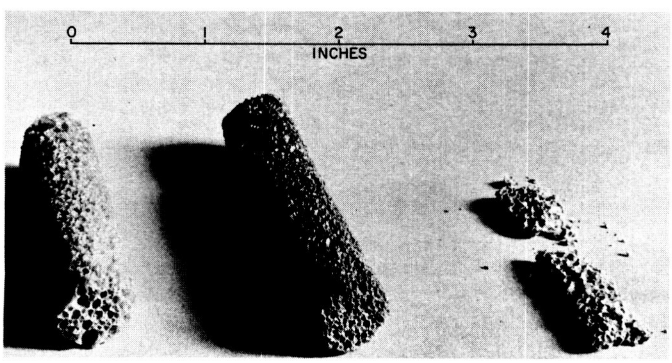


Fig. 25. Foamsil as received, after outgassing at 2000°F and after testing at 2200°F

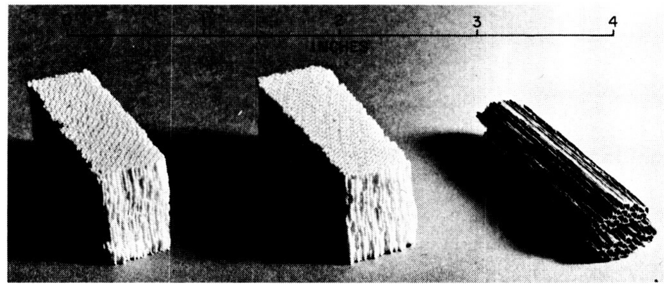


Fig. 26. Cercor as received, after outgassing at 2000°F and after testing at 2200°F

The variations observed in microhardness with Foamsil were attributed to a variation in pore size in the material and, consequently, a variation in degree of outgassing obtained. Complete devitrification produced during testing released any remaining gas in the material.

Additional tests on foamed alumina and zirconia are being undertaken. To evaluate the effectiveness of foil wrapping in protecting Cb-1Zr from oxidation, a series of capsules were wrapped with molybdenum, tantalum, and zirconium foil. These were exposed at 2200°F for 100 hr to a stream of argon containing 2 ppm oxygen. The capsules after testing are shown in Fig. 27. The tantalum wrap was in the best condition, showing slight embrittlement. The molybdenum and zirconium foils were completely embrittled. This is what would be predicted from the reaction rates of the three materials with oxygen.

To evaluate the stability of the oxide of each of the wraps, capsules of Cb-1Zr were filled with molybdenum oxide, tantalum oxide and zirconium oxide. The results of these tests, shown in Fig. 28, 29 and 30, follow thermodynamic predictions. The molybdenum oxide reacted to completely embrittle the Cb-1Zr. No reaction was ob-

Table 2. Cb-1Zr compatibility tests for insulation

Insulation	Tantalum wrap	Tensile strength, psi	Elongation, %	Microhardness	
				Surface	Center
Cercor	No	35,300	54	118	112
Cercor	Yes	34,700	52	108	111
Glassrock #25	No	35,000	52	116	111
Glassrock #25	Yes	34,200	52	114	112
Foamsil	No	34,700	55	111	110
Foamsil	Yes	35,600	50	118	118
None	No	32,800	54	109	110
None	Yes	33,900	51	113	110

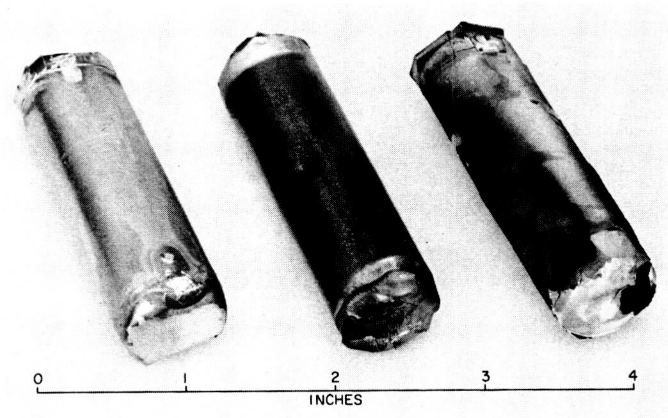


Fig. 27. Cb-1Zr capsules wrapped with molybdenum, tantalum and zirconium foil after exposure to argon containing 2 ppm oxygen at 200°F for 100 hr

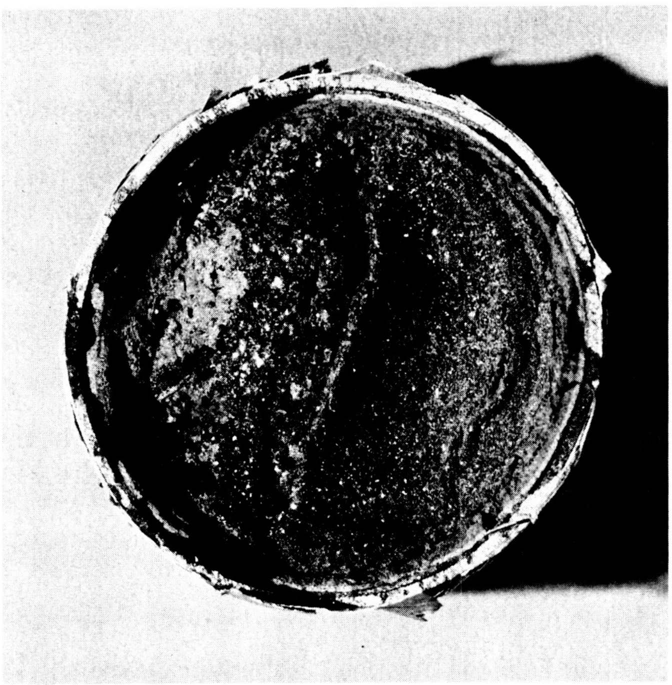


Fig. 28. Cb-1Zr capsule containing molybdenum oxide after 100 hr at 2200°F

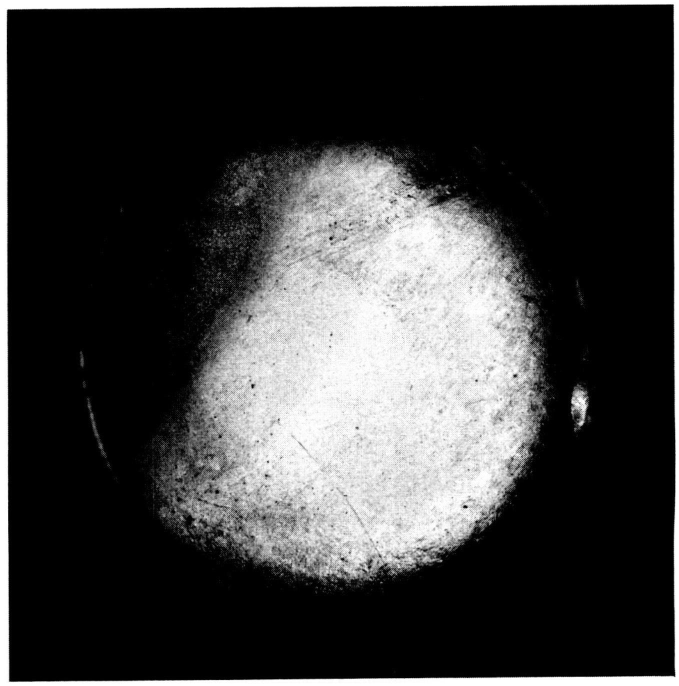


Fig. 29. Cb-1Zr capsule containing tantalum oxide after 100 hr at 2200°F

Fig. 30. Cb-1Zr capsule containing zirconium oxide after 100 hr at 2200°F

served with tantalum oxide. The zirconium oxide produced a superficial reaction layer on the columbium. This was believed to be zirconium which resulted from a change in the stoichiometry of ZrO_2 at elevated temperatures.

Test capsules are presently being wrapped with a layer of zirconium foil covered with two layers of tantalum foil. This has been found to provide better protection than any of the foils separately and may ultimately be selected as the technique for loop protection.